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LASER IMPULSE MEASUREMENTS WITH
ELECTRONIC DETECTION SYSTEM

by

Millan D. Stoller

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LASER IMPULSE MEASUREMENTS WITH ELECTRONIC DETECTION SYSTEM

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LASER IMPULSE MEASUREMENTS WITH ELECTRONIC DETECTION SYSTEM

ABSTRACT

An electronic device to determine the swing of a ballistic pendulum when the pendulum is struck by laser radiation is described and its operation analyzed.

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INTRODUCTION

This report introduces a technique for determining the horizontal displacement of a ballistic pendulum used in impulse measurement when the pendulum is struck by a laser pulse. The technique uses an assembly of miniature semiconductor photodiodes which detect light interruptions and convert the interruptions into electrical pulses which are fed into stable high gain transistor amplifiers. The amplified signals then drive bistable multivibrators which act as electronic switches to light indicator lamps on the control panel. Since the photodiodes are located at known distances in the detection assembly, the lights automatically indicate the horizontal position of the pendulum as it moves in the detection head.

DESCRIPTION

A semiconductor photodiode senses, through a tiny lens embedded in one end of its holder, light interruptions produced by the motion of a ballistic pendulum, sketched in Figure 1, swinging between a row of photodiodes and a bank of miniature lamps as pictured in Figure 2. These light interruptions cause variations in radiant energy absorption that brings about changes in photocurrent generation in the semiconductor detectors. The photoconductivity resulting from the motion of the photoelectrons in photodiodes is determined by the following relation

$$\delta = e(p\mu_p + n\mu_n) \tag{1}$$

where δ = photoconductivity

   e = electron charge

   p = hole density

   n = electron density

   μ_p = hole mobility

   μ_n = electron mobility

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θ

L   Y

x

S

x ≈ S SINCE
θ IS SMALL AND
L IS LARGE
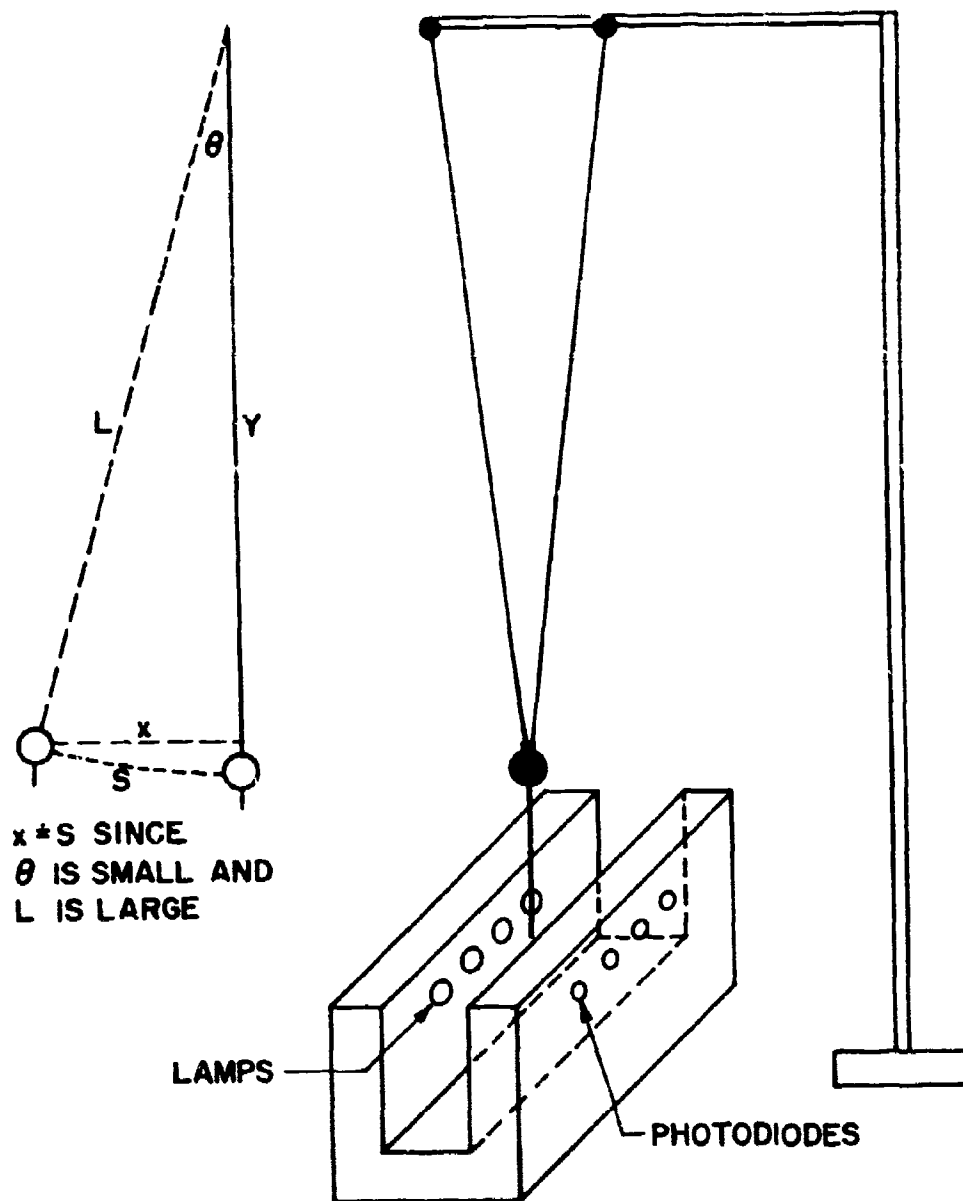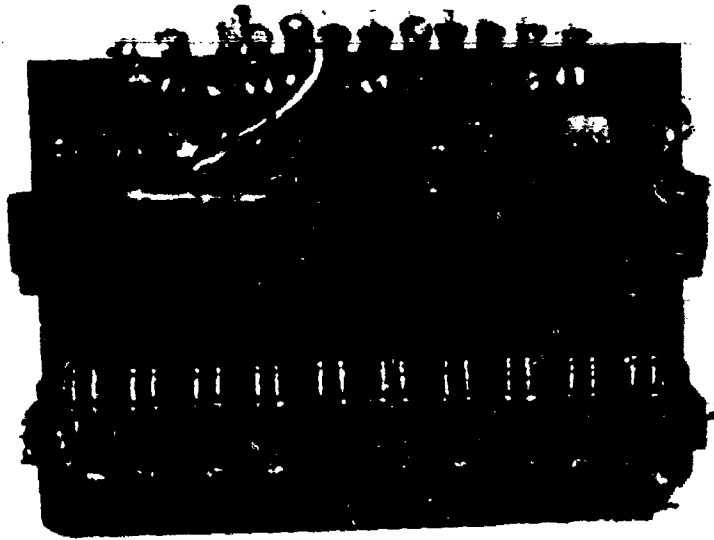
LAMPS

PHOTODIODES

Figure 1.   Ballistic pendulum

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Figure 2. Photodetector head assembly

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Photodiodes, made of intrinsically pure silicon, have their hole
density equal to their electron density, so that $p = n = n_i$. Equation (1)
now becomes

$$\delta = en_i(u_p + u_n)$$

$$= 1.6 \times 10^{-19} \times 1.6 \times 10^{10} (500 + 1500)^{*} \quad (2)$$

$$= 5.14 \times 10^{-6} \text{ mho/cm}$$

But
$$R = \frac{1}{\delta} = \frac{1}{5.14 \times 10^{-6}}$$

$$= 1.95 \times 10^{5} \text{ ohm-cm} .$$

The dimensions of the photodiode are such that, when numerical
values are substituted in Equation (3) resistivity becomes 195 Kilohms:

$$R' = R(L/A) \quad (3)$$

where R' = resistance

R = resistivity

L = length

A = area.

This value of resistance indicates that the load resistance R_L in the
photodiode circuit, Figure 3, should be around 195 kilohms. Data on
the transistor used in the circuit show that this resistance is too
high to match the input resistance of the transistor amplifier. We had
a choice either to use a transformer with high primary and low secondary
impedances or to use a lower value of load resistor R_L than the above
computations indicate. Since transformers are bulky and not well suited
for printed-board circuity, a decision to use the lower value load
resistor was made.

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[*] *A. H. Seidman and S. L. Marshal, Semiconductor Fundamentals, Wiley, 1963.*
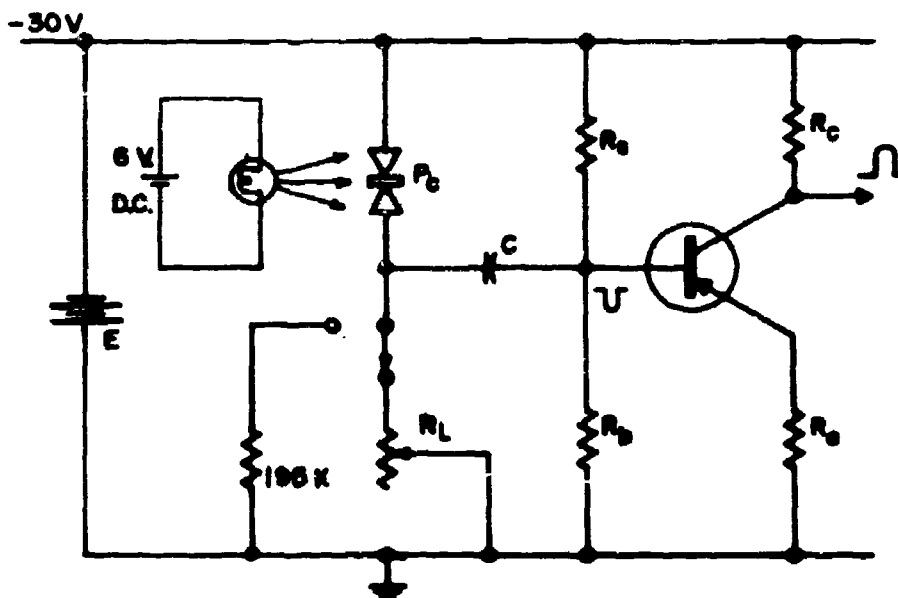
Figure 3. Photodetector circuit

A circuit having a 195-kilohms load resistor was first tried. We found that the detector functioned properly when not in the transistor amplifier circuit. When coupled to the amplifier, the output from the amplifying stage was badly distorted. So a variable load resistor with a 4-µf capacitor was used to determine an acceptable value of resistance that would give optimum output signal. In this manner the 39-kilohm load resistor was chosen and used as part of the electronic switch system shown in Figure 4.

As the signals produced by pendulum motion between a row of silicon photodiodes and a bank of lighted miniature lamps strike the photodiode lens, the light signals are converted into photocurrents which flow through the 39-kilohm resistor to the minus 30-volt terminal. Voltage variations thus developed by the photocurrents across the load resistor are then impressed on the 4-uf coupling capacitor where they are sensed by the base of the stabilized pnp transistor amplifier. The output from the amplifier is then directed to the bistable multivibrator which acts as an electronic switch shown schematically in Figure 4.

ANALYSIS

The controlling element of the electronic switch is a bistable multivibrator, having two independent transistor stages. Each stage has a separate input circuit for initiating desired stage operation, enabling the switch to respond to an input introduced into the switching circuit by either the photodiode-set signal or an external manually-controlled reset signal. Thus either of the alternate states of the bistable circuit can impose a desired operating condition on the switch and cause it to maintain that operating state until it receives another command to change its current state.

The schematic diagram shown in Figure 4 shows in detail one complete unit of the electronic switch with the "set" and "reset" circuitry. When the power is turned on, and the flip-flop is reset, then transistor Q_2 starts to conduct. When the pendulum swings in front of the photodiode, the light interruption causes the photodiode to develop a signal which
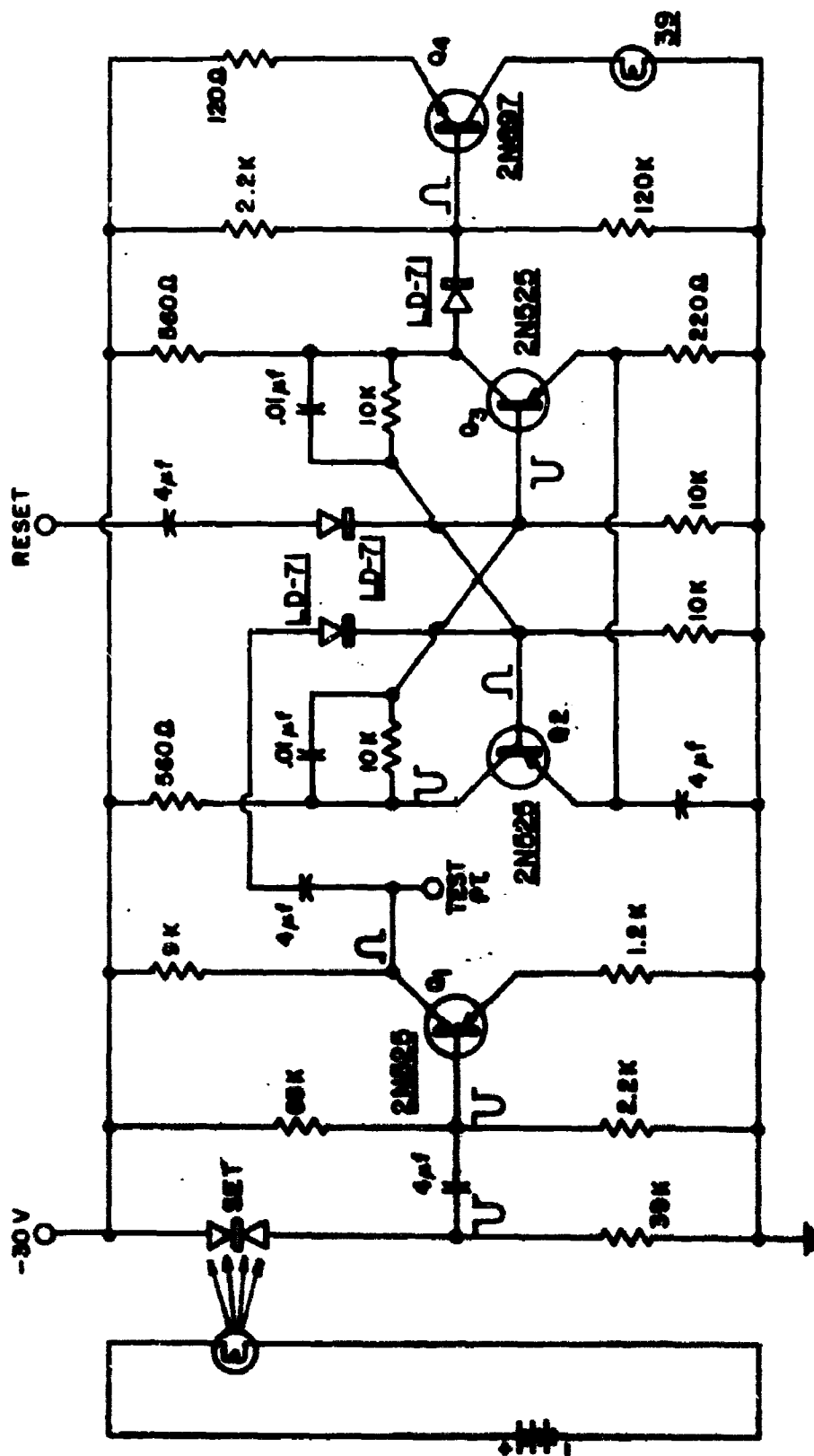
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Figure 4. Photodetector electronic switch

is amplified and fed through diode LD-71 to the base of the transistor Q_2. This pulse drives transistor Q_2 into the "cutoff" state and transistor Q_3 into its "on" state. The latter transistor remains in the "on" condition until it is manually reset into its "off" state. While in its conducting state, transistor Q_3 drives transistor Q_4 into conduction which lights the designated indicator lamp located on the control panel.

The twelve photodiodes with associated electronic circuitry constitute the pendulum displacement detection system. The distances between the photodiode centers are fixed at 3 mm. Photodetector No. 1, lighting lamp No. 1, is used as a reference position. When the pendulum, with an attached pointer to interrupt light incident on the sensors, is struck by a laser pulse; the impact sets the pendulum in motion. Successive photodetectors sense the passage of the pointer and generate electric signals. After sufficient amplification, these signals turn on the associated indicator lamps on the control panel. The last lighted lamp shows the maximum pendulum displacement.

For example, if the first seven lamps on the control panel are lighted, the maximum displacement with reasonable certainty can be assumed to be $(7-1) \times 3 + 1.5 = 19.5$mm, where 1.5mm is the best estimate of the average displacement error. The last sensing detector indicates that the pointer has definitely reached, and probably has passed, its central position, but has not gone far enough to activate the next sensor. The pendulum pointer is so set over the reference photodiode that it has to move close to 3mm before it is detected by the next succeeding detector. The uncertainty of the exact location of the pointer after the last activated diode necessitates the consideration of the average constant error of 1.5mm. This inherent error causes a significant error when the pendulum displacement is small, but it becomes almost insignificant when the displacement is large.

Since this system can be used in a vacuum where a telescope cannot most likely be used, or in a place where it would not be safe for a man to observe visually the pendulum displacement, the system is of importance even with its small inherent error. The table given below shows distances that may be displaced by the ballistic pendulum and correspondingly recorded by indicator lamps on the control panel.

Table of Indicator Lamp Distances

Lamp No.	1	2	3	4	5	6	7	8	9	10	11	12
Distance Cm	0	.3	.6	.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3

Thus, when a laser pulse strikes the pendulum, and the panel lights go on from 1 through 11, the pendulum has swung 3 cm. Using the following mathematical expression for impulse calculation, we obtain the numerical value of the impulse.

$$I = M \sqrt{g/L} \; x = 5 \sqrt{980/100} \; x \; 3 = 47 \text{ dyne-seconds.}$$

Where M is the pendulum mass, L is the pendulum length in centimeters, and X is the pendulum horizontal displacements.

CONCLUSION

The unique feature of the electronic detection system described above is the convenience with which pendulum swings can be recorded. This displacement measuring technique has demonstrated that the system is sufficiently accurate for use in laser-produced impulse experiments. Because of its convenience, accuracy, and reliability, this system is expected to prove quite useful in further experiments with laser impulse measurements.

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13. ABSTRACT

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KEY WORDS	LINK A		LINK B		LINK C	
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Electronic						
Laser Impulse						
Measurement						